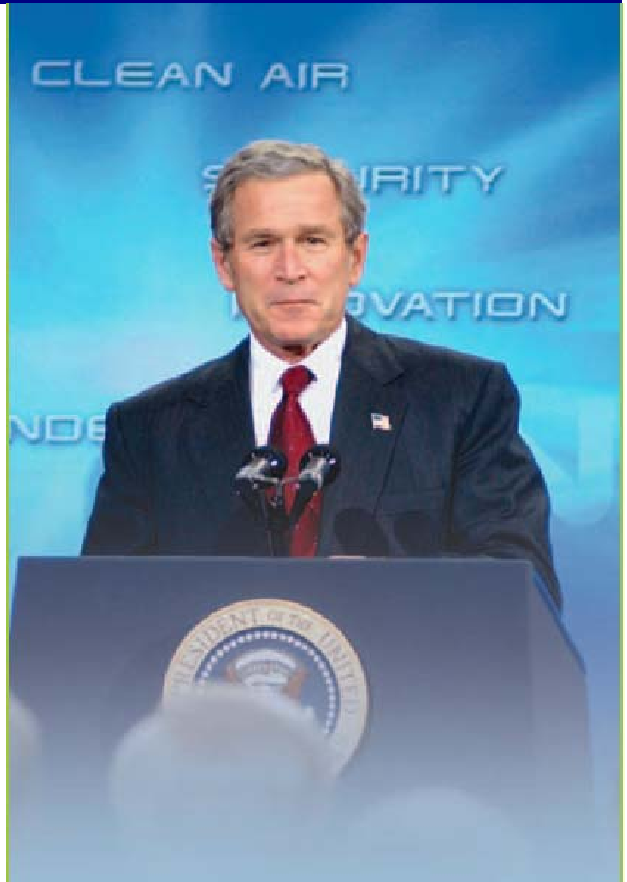
Executive Summary

President Bush launched the Hydrogen Fuel Initiative to ensure our nation's long-term energy security and a clean environment. Using hydrogen to fuel our economy can reduce U.S. dependence on imported petroleum, diversify domestic energy sources, and reduce pollution and greenhouse gas emissions. Fuel cells are an important enabling technology for a future hydrogen economy and have the potential to revolutionize the way we power our nation, offering cleaner, more efficient alternatives to today's technology.

Energy Security: The U.S. uses about 20 million barrels of oil per day (60% of which is imported), at a cost of about $6 billion a week (assumes a cost of $45 per barrel of oil). Much of this oil is used to power highway vehicles. Over 97% of our transportation energy is from petroleum. Because hydrogen can be derived from a variety of domestically-available primary sources (hydrogen itself is not a primary resource), including fossil fuels, renewable resources, and nuclear power, its use would allow us to diversify our transportation energy supply and make us less reliant upon foreign energy sources.

Additionally fuel cells are significantly more energy efficient than combustion-based power generation technologies. Internal combustion engines in today's automobiles convert less than 30 percent of the energy in gasoline into engine power for moving the vehicle. Vehicles using electric motors powered by hydrogen fuel cells have 2-2.5 times the thermal efficiency of internal combustion engines.

Environmental Benefits: Fuel cells powered by pure hydrogen emit no harmful pollutants, only pure water. Hydrogen generation and carbon-management technologies can be developed, which can significantly reduce pollutants and greenhouse gases from fossil-based hydrogen production. As a transportation fuel, it will be much easier to manage and contain greenhouse gas emissions from stationary hydrogen generation sources than from the tailpipe of internal combustion engine vehicles. Using renewable or nuclear-based hydrogen in high-efficiency fuel cells to fuel our vehicles and to generate power could virtually eliminate greenhouse gas emissions and air pollution.



"With a new national commitment, ... the first car driven by a child born today could be powered by hydrogen, and pollution-free."

– **President Bush**
State of the Union Address
January 28, 2003

"Government coordination of this huge undertaking will help resolve one of the difficulties associated with the development of a commercially viable hydrogen fuel-cell vehicle:… Which comes first, the vehicle or the infrastructure of manufacturing plants, distribution and storage networks, and the convenient service stations needed to support it?…[The Department will work with all stakeholders] to develop both the vehicle and the infrastructure in parallel—and by so doing, advance a commercialization decision by 15 years, from 2030 to 2015."

— Energy Secretary Abraham
2004 DOE Budget Submission
February 3, 2003

Economic Competitiveness: Heavy dependence on imported oil threatens America's economic well-being. Small changes in the price of crude oil or disruptions to oil supplies can have big impacts on our economy, from trade deficits, to industrial investment, to employment levels. Hydrogen's diversity in production and flexibility in use offers opportunities for new technologies and players in energy markets, broadening our energy choices and increasing economic growth both at home and around the world. In addition, developing and leading the way in hydrogen fuel cell technologies for automobiles will help the U.S. to maintain its future economic competitiveness in the worldwide automotive industry.

Path Forward: Addressing Barriers to a Hydrogen Economy

The transition of our current energy infrastructure to a clean and secure energy infrastructure based on hydrogen will take decades. The technology, economic and institutional barriers pose difficult challenges. The "critical path" barriers to a hydrogen economy are:

Technology Barriers

- Hydrogen storage systems for vehicles are inadequate to meet customer driving range expectations (>300 miles) without intrusion into vehicle cargo or passenger space.
- Hydrogen is currently three to four times as expensive as gasoline.
- Fuel cells are about five times more expensive than internal combustion engines and do not maintain performance over the full useful life of the vehicle.

Economic and Institutional Barriers

- Investment risk of developing a hydrogen delivery infrastructure is too great given technology status and current hydrogen vehicle demand.
- Uniform model codes and standards to ensure safety, insurability and fair global competition are lacking.
- Local code officials, policy makers and the general public lack education on hydrogen benefits and on safe handling and use.

Defining Success and Measuring Progress

Success for the Hydrogen, Fuel Cells & Infrastructure Technologies Program is defined as validation, by 2015, of technology for:

- Hydrogen storage systems enabling greater than 300-mile vehicle range while meeting identified packaging, cost, and performance requirements
- Hydrogen production from diverse pathways to safely and efficiently deliver hydrogen to light duty hydrogen fuel cell

vehicles cost competitively on a per mile basis without adverse environmental impacts.

- Fuel cells to enable engine costs of less than $50/kW (in high volume production) and stationary power production at $400-700/kW while meeting performance and durability requirements

If these indicators are met, there is a high probability of success that customer requirements can be met, and that industry will begin to realize a business case for proceeding with a positive commercialization decision regarding hydrogen infrastructure and fuel cell vehicles. While the full extent of life-cycle cost and energy and environmental impacts will not be achieved for decades, a positive commercialization decision in 2015 will begin to yield national benefits as early as 2025. To assist in measuring interim progress towards the 2015 commercialization decision, the following program objectives have been established with industry input. Key milestones will be monitored by the Office of Management and Budget within the Executive Office of the President:

Hydrogen Production

Reduce the cost of hydrogen to $2.00 - $3.00/gge[1] (delivered, untaxed) at the pump by 2015.[2]

- Reduce the cost of distributed production of hydrogen from natural gas to $2.50/gge (delivered, untaxed) at the pump (without carbon sequestration) by 2010; and reduce the cost of distributed hydrogen production from biomass-derived renewable liquids to $2.00 - $3.00/gge (delivered, untaxed) at the pump by 2015.
- Verify grid-connected distributed water electrolysis at a projected delivered hydrogen cost of $2.85/gge by 2010, and by 2015, verify central hydrogen production from renewable energy sources at a projected cost of $2.75/gge delivered.
- Reduce the cost of hydrogen produced from biomass to $1.60/gge at the plant gate ($2.60 delivered) by 2015.
- Develop advanced renewable photoelectrochemical and biological hydrogen generation technologies. By 2015, verify the feasibility of these technologies to be cost-competitive in the long term.

"There are two paths we need to follow: research and development, and public outreach to capture the imagination of the American people. This will be a long journey and process, and the Department of Energy will work with you as we move forward."

David Garman, Assistant Secretary for Energy Efficiency and Renewable Energy
National Hydrogen Energy Roadmap Workshop
April 2-3, 2002

Hydrogen Cost Goal

In 2005, the Department of Energy developed a new hydrogen cost goal for the 2015 commercialization decision. The hydrogen cost goal, which is independent of the production pathway, was adjusted to $2.00-$3.00 per gallon of gasoline equivalent (gge) based on the Energy Information Agency's forecast of gasoline cost in 2015, and the relative fuel economy of hydrogen fuel cell vehicles to advanced vehicle technology in 2015. The methodology used ensures that consumers' operating cost ($/mile) in a hydrogen fuel cell vehicle will be equal to or less than the competitive gasoline vehicle in 2015.

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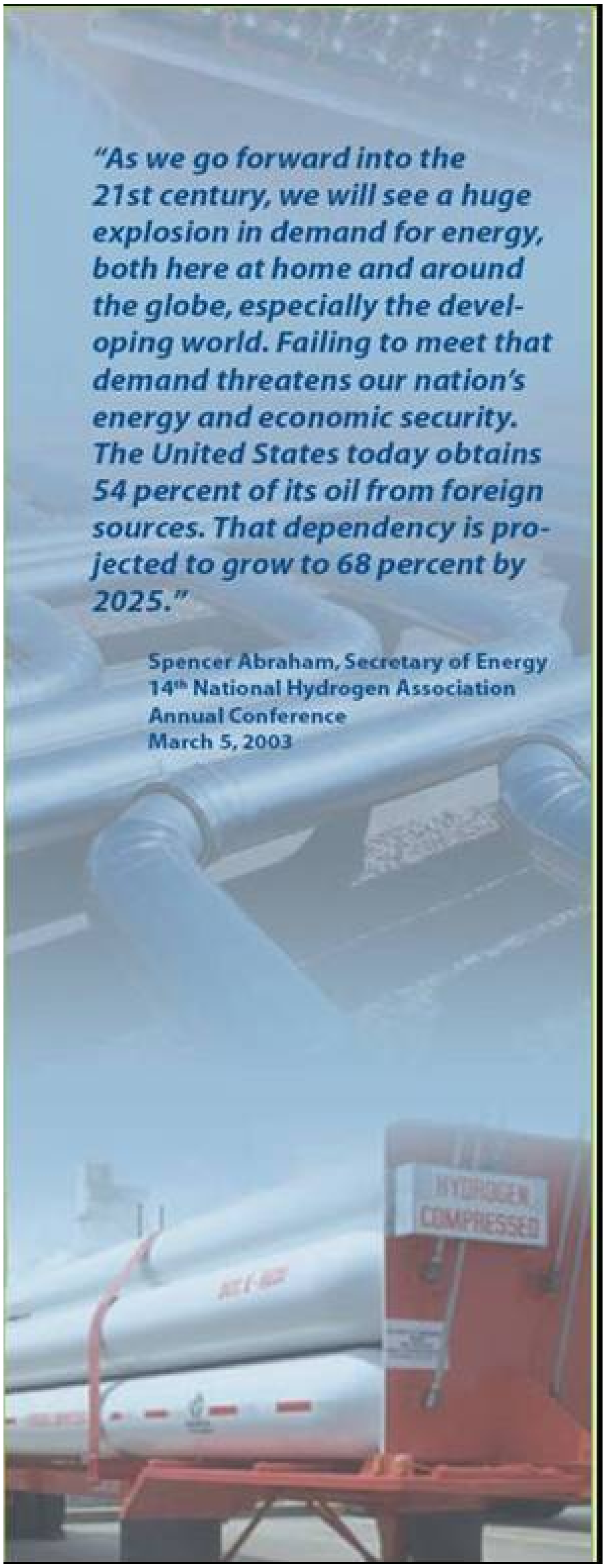
[1] One gallon of gasoline is approximately equal to one kilogram of hydrogen on an energy basis.

[2] This cost range results in equivalent fuel costs per mile for a hydrogen fuel cell vehicle compared to gasoline internal combustion engine and gasoline hybrid vehicles. The full explanation and basis for the hydrogen cost goal can be found in DOE Record 5013 (see www.hydrogen.energy.gov/program_records.html)



- Research and develop high-temperature thermochemical cycles driven by concentrated solar power processes to produce hydrogen with a projected cost of $3.00/gge at the plant gate ($4.00 delivered) by 2015.

Hydrogen Delivery

- By 2010, develop technologies to reduce the cost of hydrogen delivery from central and semi-central production facilities to the gate of refueling stations and other end users to <$0.90/gge of hydrogen and to reduce the cost of compression, storage and dispensing at refueling stations and stationary power facilities to <$0.80/gge of hydrogen.
- Develop enabling technologies to reduce the cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units to <$1.00/gge of hydrogen by 2015.

Hydrogen Storage

- By 2010, develop and verify on-board hydrogen storage systems achieving 2 kWh/kg (6 wt%), 1.5 kWh/L, and $4/kWh. By 2015, 3 kWh/kg (9 wt%), 2.7 kWh/L, and $2/kWh.

Fuel Cells

- Develop a 60% peak-efficient, durable, direct hydrogen fuel cell power system for transportation at a cost of $45/kW by 2010 and $30/kW by 2015.
- Develop a distributed generation polymer electrolyte membrane (PEM) fuel cell system operating on natural gas or liquid petroleum gas that achieves 40% electrical efficiency and 40,000 hours durability at $400-$750/kW by 2010.

Technology Validation

- By 2009, validate hydrogen vehicles that have greater than 250-mile range and 2,000-hour fuel cell durability, with hydrogen infrastructure that results in a hydrogen production cost of less than $3.00/gge (delivered, untaxed).
- By 2015, vehicles that have 300+ mile range and 5,000 hours fuel cell durability, with a hydrogen production cost of $2.50/gge (delivered, untaxed).
- •Validate an Electrolyzer that is powered by a wind turbine at a capital cost of the Electrolyzer of $400/kWe and 65% efficiency, including compression to 5,000 psi, (when built in quantities of 1,000) by 2008.

- Validate an integrated biomass/wind or geothermal Electrolyzer system to produce hydrogen for $2.85/gge at the plant gate (untaxed) by 2011.

Codes and Standards

- By 2006, complete research and development on hydrogen release scenarios, providing a sound basis for model code development and adoption.
- Support and facilitate the drafting and adoption of model building codes for hydrogen applications by the National Fire Protection Association and the ICC by 2007.
- Support and facilitate the completion of the ISO standards for hydrogen refueling and on-board storage by 2007.
- Support and facilitate development of Global Technical Regulations (GTR) for hydrogen vehicle systems by 2010.
- By 2015, ensure necessary codes and standards are completed that support the commercialization of hydrogen technologies.

Safety

- In collaboration with industry, develop a comprehensive hydrogen safety plan by 2005 that establishes Program safety policy and guidelines.
- Integrate safety procedures into new DOE project-funding procurements to ensure that all projects incorporate hydrogen safety requirements.
- Publish a handbook of "Best Management Practices for Safety" by 2007.
- Continuously develop supporting research and development program to provide critical hydrogen behavior data and hydrogen sensor and leak detection technologies to support the establishment of building codes.
- Continuously promote widespread sharing of safety-related information, procedures and lessons-learned to first responders, jurisdictional authorities and other stakeholders.

Education

- By 2010, achieve a fourfold increase (from 2004 baseline) in the number of state and local government representatives, students and teachers, and a twofold increase in the number of large-scale end users who understand the concept of a hydrogen economy, and how it may affect them.
- Launch a comprehensive and coordinated public education campaign about the hydrogen economy and fuel cell technology by 2010.

Systems Analysis

Educating consumers, industry leaders, and public policy makers about the benefits of hydrogen is critical to achieving the vision.

> ***"It is important that all aspects of the various conceivable hydrogen system pathways be adequately modeled to understand the complex interactions between components, system costs, environmental impacts of individual components and the system as a whole, societal impacts (e.g., offsets of imported oil per year), and possible system trade-offs."***
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> **–National Academies' Committee on Alternatives and Strategies for Future Hydrogen Production and Use, April 2003 Letter Report**

- Through analysis, support the integration of the Program within a balanced, overall DOE national energy R&D effort addressing the role of hydrogen in context of the overall energy infrastructure.
- By 2007, identify and evaluate transition scenarios consistent with developing infrastructure and hydrogen resources, including an assessment of timing and sequencing issues.
- Provide and/or coordinate appropriate and timely analysis of environmental and technoeconomic issues to support decision-making tied to Program schedules, targets and milestones.
- By 2008, develop a macro-system model of the hydrogen fuel infrastructure to support transportation systems. By 2010, enhance the model to include the stationary electrical generation and infrastructure for a full hydrogen economy.
- Support a spectrum of analyses, including financial and environmental assessments, across and within Program elements—from individual unit/subsystem elements to a fully integrated system and infrastructure.

Systems Integration

- By 2005, establish an integrated technical and programmatic baseline, and maintain and utilize the baseline to support programmatic decisions and ensure research and development directions satisfy needs.
- Verify that the system being developed satisfies the Program requirements, projects are meeting performance and milestone objectives, and progress toward technical targets is substantiated.
- Provide analyses and recommend DOE-sponsored activities to enable the commercial sector to deploy a well-integrated hydrogen system that satisfies needs while continually monitoring system performance to identify potential improvements.

Tracking Progress and Achieving Success

Putting it all together is the ultimate challenge. To achieve the goal of commercially-viable hydrogen and fuel cell systems in the 2015 timeframe:

- R&D efforts must be focused on the most promising technologies
- Customer requirements must be validated in a fully-integrated operating system.

DOE has identified the key Program milestones necessary to meet these technical targets (see Appendix B). These milestones support the critical path technologies outlined by DOE. Each of the timelines specify a delivery date for the given technology development, improvement or demonstration. As technologies evolve and economic and systems analyses data become available, these targets will be refined.

The Hydrogen, Fuel Cells & Infrastructure Technologies Program is emphasizing a results-driven management approach, in accordance with the principles laid out in the President's Management Agenda, to ensure that efforts are continually refocused on technologies that are most likely to achieve the goals of the Program. The technical targets provide clear quantifiable measures, which can be used to track progress and to show the return on investment of taxpayer dollars. Periodic milestones and Go/No-Go decision points ensure that performance is linked to budget and that funds will be used only for the most promising technology approaches as performance goals are being met along the way. The technological advancements in each Program element and lessons learned from successful demonstrations of hydrogen and fuel cell technologies must be integrated to work together as a fully functional system.

As we look to the future, hydrogen and fuel cell technologies appear to be viable in meeting the long-term energy needs of the nation. The DOE is building partnerships with universities, national laboratories, industry and the international community to speed up the development of hydrogen technologies. Together, we will realize our vision of a hydrogen energy future.

"The effective management of the Department of Energy hydrogen program will be far more challenging than any activity previously undertaken on the civilian energy side of the DOE."

– National Academies' Report, "The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs" February 2004